11-06-00

A/RE

By Express Mail #EL645964553US
November 3, 2000

Attorney Docket No.: **4136-20CPRE**

Check box if applicable: ☐ *DUPLICATE*

REISSUE PATENT APPLICATION TRANSMITTAL
UTILITY PATENT

Assistant Commissioner for Patents
BOX PATENT APPLICATION
Washington, DC 20231

Dated: November 3, 2000

Sir:

Transmitted herewith for filing is the utility patent application of:

Inventor: Ronald B. Lavochkin
Original Patent No.: 5,829,516
Original Patent Issue Date: November 03, 1998
For: Liquid Cooled Heat Sink for Cooling Electronic Components

Enclosed are:

1. Transmittal letter **(2x)** with Fee Computation Sheet
2. General Authorization For Payment of Fees **(2x)**
3. Title Page, Specification, Claims 1 to 32 & Abstract (19 total pages of application) *as amended*
4. Unexecuted Reissue Declaration and Power of Attorney by Assignee (2 pages)
5. 9 sheets of drawings (Figs. 1 to 21)
6. Unexecued Offer to Surrender Original Patent by Assignee
7. Unexecuted Certificate Under 37 C.F.R. 3.73(b)
8. Copy of Assignments & Recordation Cover Sheets from prior application
9. Check for **$1,210** for filing fee
10. Return Receipt Postcard

[x] Original U.S. Patent is currently assigned. Written Consent of All Assignees (Offer to Surrender Original Patent by Assignee PTO/SB/54) is enclosed.

[] Verified Statement Claiming Small Entity Status was filed in prior application. Status still proper and desired.

By Express Mail #EL645964553US
November 3, 2000

[] Please charge my Deposit Account No. 03-2412 in the amount of $_. A duplicate copy of this sheet is enclosed.

[x] The Commissioner is hereby authorized to charge payment of the following fees associated with this application or credit any overpayment to Deposit Acct. No. 03-2412.

- [x] Any additional filing fees required under 37 CFR 1.16.
- [x] Any patent application processing fees under 37 CFR 1.17 not otherwise paid by check.
- [x] The issue fee set in 37 CFR 1.18 at 3 months from mailing of the Notice of Allowance, pursuant to 37 CFR 1.311 (b) provided the fee has not already been paid by check.
- [x] Any filing fees under 37 CFR 1.16 for presentation of extra claims.

Respectfully submitted,
COHEN, PONTANI, LIEBERMAN & PAVANE

By:________________________
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Dated: November 3, 2000

Attorney Docket No.: **4136-20CPRE**

REISSUE APPLICATION FEE TRANSMITTAL FORM

Submit an original and a duplicate for fee processing

Assistant Commissioner for Patents
BOX PATENT APPLICATION
Washington, DC 20231

Dated: November 3, 2000

In re Reissue Application of: Ronald B. Lavochkin
Original Patent No.: 5,829,516
Original Issue Date: November 03, 1998
For: Liquid Cooled Heat Sink for Cooling Electronic Components

The filing fee has been calculated as shown below:

FOR:	Col. 1	Col. 2	SMALL ENTITY	OTHER THAN SMALL ENTITY
	# FILED	# EXTRA		
BASIC FEE			**$380**	**$760**
TOTAL CLAIMS	32 - 20 =	12	x 9 = $	12 x 18 = **$216**
INDEPENDENT CLAIMS	6 - 3 =	3	x 39 = $	3 x 78 = **$234**
[] MULTIPLE DEPENDENCY			+$130 = $	+ 260 $
* If the difference in Col. 1 is less than zero, enter "0" in Col. 2			TOTAL: $	**$1210**

By Express Mail
No. EL645964553US

REISSUE APPLICATION DECLARATION AND POWER OF ATTORNEY BY THE INVENTOR

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor of the subject matter which is described and claimed in patent number **5,829,516,** granted **November 03, 1998**, and for which a reissue patent is sought on the invention entitled

LIQUID COOLED HEAT SINK FOR COOLING ELECTRONIC COMPONENTS

the specification of which is attached hereto.

I hereby state that I reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the patentability of this application in accordance with Title 37, Code of Federal Regulations, Section 1.56(a).

I verily believe the original patent to be wholly or partly inoperative or invalid, for the reasons described below. (Check all boxes that apply)

[] by reason of a defective specification or drawing.

[x] by reason of the patentee claiming more or less than he had the right to claim in the patent.

[] by reason of other errors.

At least one error upon which reissue is based is described as follows:

The claims covered less than applicant had the right to claim in the patent.

All errors corrected in this reissue application arose without any deceptive intention on the part of the applicant.

As a named inventor, I hereby appoint the following attorneys and/or agents to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith:

MYRON COHEN, Reg. No. 17,358; THOMAS C. PONTANI, Reg. No. 29,763; LANCE J. LIEBERMAN, Reg. No. 28,437; MARTIN B. PAVANE, Reg. No. 28,337; MICHAEL C. STUART, Reg. No. 35,698; KLAUS P. STOFFEL, Reg. No. 31,668; EDWARD M. WEISZ, Reg. No. 37,257; JULIA S. KIM, Reg. No. 36,567; VINCENT M. FAZZARI, Reg. No. 26,879; ALFRED W. FROEBRICH, Reg. No. 38,887; KENT H. CHENG, Reg. No. 33,849; GEORGE WANG, Reg. No. 41,419; TZVI HIRSHAUT, Reg. No. 38,732, GERALD J. CECHONY, Reg. No. 31,335; ROGER S. THOMPSON, Reg. No. 29,594; JOY I. FARBER, Reg. No. 44,103; and GEORGE J. BRANDT, JR., Reg. No. 22,021.

Address all telephone calls to Martin B. Pavane, Esq. at telephone No. (212) 687-2770.

Address all correspondence to:

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551 Fifth Avenue, Suite 1210
New York, New York 10176

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full Name of Sole or First Inventor: Ronald B. Lavochkin

Inventor's signature: ______________________________

Dated: ______________________
Month/Day/Year

Residence: **24 Cedar Lane, Bow, New Hampshire, 03304**

Citizenship: **United States of America**

Post Office Address:

By Express Mail #EL645964553US
November 3, 2000

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In Re Reissue Application
Original Patent No.: 5,829,516
Original Issue Date: November 03, 1998
Patentees: Ronald B. Lavochkin
Title: Liquid Cooled Heat Sink for Cooling Electronic Components

Assistant Commissioner for Patents
Washington, D.C. 20231

REISSUE APPLICATION BY ASSIGNEE
OFFER TO SURRENDER, ASSENT TO REISSUE

Assistant Commissioner for Patents
Washington, D.C. 20231

Aavid Thermal Products, Inc. is now owner by assignment of the entire interest in U.S. Patent Number 5,829,516, entitled "Liquid Cooled Heat Sink for Cooling Electronic Components" issued November 03, 1998, to Ronald B. Lavochkin. Filed herewith is a Certificate under 37 CFR 3.373(b).

Aavid Thermal Products, Inc. hereby offers to surrender U.S. Patent Number 5,829,516.

Aavid Thermal Products, Inc. hereby assents to the accompanying application which seeks reissue of U.S. Patent Number 5,829,516.

Date: ________________ Aavid Thermal Products, Inc.

Signature: ______________________________
Name: ______________________
Title: ______________________

EMS Priority Mail EL645964553US

Attorney Docket No.: 4136-20CPRE | Patent

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In Re Reissue Application
Original Patent No.: 5,829,516
Original Issue Date: November 03, 1998
Patentees: Ronald B. Lavochkin
Title: Liquid Cooled Heat Sink for Cooling Electronic Components

Assistant Commissioner for Patents
Washington, D.C. 20231

CERTIFICATE UNDER 37 CFR 3.73(b)

Aavid Thermal Products, Inc. (Name of Assignee), a (Type of Assignee, e.g. a corporation, partnership, university, government agency, etc.), states that it is:

[x] the assignee of the entire right, title and interest; or

[] an assignee of an undivided part interest

in the patent identified above by virtue of either:

A. [x] An assignment from the inventor of the patent identified above. The assignment was recorded in the Patent and Trademark Office at Reel 7971, Frame 0136 on 02/20/1996.

AND

B. [x] A chain of title from the inventor, of the patent identified above, to the current assignee as shown below:

1. From: Aavid Engineering, Inc. To: Aavid Thermal Products, Inc.
The document was recorded in the Patent and Trademark Office at
Reel 9437, Frame 0018 on 07/23/1998.

[ ] Additional documents in the chain of title are listed on a supplemental sheet.

[X] Copies of assignments or other documents in the chain of title are attached.

[**NOTE**: A separate copy (i.e., the original assignment document or a true copy of the original document) must be submitted to Assignment Division in accordance with 37 C.F.R. Part 3, if the assignment is to be recorded in the records of the PTO. See MPEP 302-302.8]

The undersigned (whose title is supplied below) is empowered to act on behalf of the assignee.

I hereby declare that all statements made herein of my own knowledge are true, and that all statements made on information and belief are believed to be true; and further, that these statements are made with the knowledge that willful false statements, and the like so made, are punishable by fine or imprisonment, or both, under Section 1001, of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Date: ______________ Name: ______________________________

Title: ______________________________

Signature: ______________________________

By Express Mail #EL645964553US November 3, 2000

Attorney Docket # 4136-20CPRE

Patent

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Reissue Application of

Ronald B. Lavochkin

Original Patent No.: 5,829,516

Original Issue Date: November 03, 1998

Title: Liquid Cooled Heat Sink for Cooling Electronic Components

Check box if applicable:
☐ DUPLICATE

jc914 U.S. PTO
09/706295
11/03/00

GENERAL AUTHORIZATION FOR PAYMENT OF FEES AND PETITIONS FOR EXTENSIONS OF TIME

Assistant Commissioner for Patents
BOX PATENT APPLICATION
Washington, DC 20231

Sir:

The Commissioner is hereby authorized to credit overpayments or charge the following fees to Deposit Account No. 03-2412

[X] Any filing fees required under 37 CFR §1.16.

[X] Any patent application processing fees under 37 CFR §1.17 not otherwise paid by check.

[X] The issue fee set in 37 CFR 1.18 at 3 months from mailing of the Notice of Allowance, pursuant to 37 CFR 1.311 (b) provided the fee has not already been paid by check.

[X] Any filing fees under 37 CFR 1.16 for presentation of extra claims.

Respectfully submitted,
COHEN, PONTANI, LIEBERMAN & PAVANE

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09706295.110300

By Express Mail
No. EL645964553US

APPLICATION FOR
UNITED STATES LETTERS PATENT

LIQUID COOLED HEAT SINK FOR COOLING ELECTRONIC COMPONENTS

Inventor: **Ronald B. Lavochkin**

RELATED APPLICATIONS

This patent application is a continuation in part of my patent application, Ser. No. 08/166,871 filed Dec. 15, 1993, now abandoned, and assigned to the same assignee as the present invention.

FIELD OF THE INVENTION

The present invention relates to improvements in heat sinks for cooling heat generating components and particularly for cooling electronic components.

DISCUSSION OF THE RELATED ART

Electronic semiconductor components, and other heat generating sources, have power handling limitations which are determined by several factors. All electronic components, while extremely efficient, incur some internal losses in the creation of useful work. The internal losses of energy are caused by circuit resistances or change in conduction states. This energy is expressed in the form of heat which, if not properly controlled or removed, will cause the internal temperature (or energy state) to reach a point where the electronic device will not properly operate. Since it is the objective of the electronic component end user to extract as much useful work as possible out of the component, the component manufacturer will create an internal structure that will either minimize the losses or if that is not adequate, provide an efficient thermal path for conduction (or transferal) of the heat energy out of the component. If it is the latter, an external component, normally referred to as a "heat sink", is used to absorb the heat energy and, ultimately, transfer it to whatever replenishable cooling fluid is available to the end user.

Heat energy (which is continuously generated by the operating component), once created, can only "flow" from a hot region to a relatively cold region. The rate (or ease) at which this energy can be transferred is primarily determined by three modes of heat transfer. The first is conductive heat transfer. This mechanism is based on the ability of any solid material to conduct heat through itself. The key parameters are: available temperature difference (ΔT), the material's conductivity (k), the length of the thermal path (l) and the cross-sectional area (A) through which the heat has to flow. This can be expressed in an equation as:

$$Q=kA\Delta T/l$$

The second mechanism is convective heat transfer. This is based on the ability of a replenishable fluid (typically air or water) to absorb heat energy through intimate contact against a hotter solid surface. Its key parameters are: available temperature difference (ΔT), the fluid's absorptive characteristics (h) and the amount of surface contact area (A). This is expressed as:

$$Q=hA\Delta T$$

The final mechanism is radiative heat transfer. This is based on the emission of low level energy waves from a solid surface to distant cooler surfaces or fluid molecules; similar to heat radiated from a fireplace. It is dependent on: available temperature difference (ΔT), the emissivity of a surface (E), the amount of exposed surface area to radiate (A). This can be expressed as:

$$Q=EA\Delta T$$

It is the interaction of these three modes that determines how easily heat energy is transferred away from the critical operating surfaces of a component (like a semiconductor device). In the typical use of a heat generating component, the heat energy first flows, via conduction heat transfer, to the cooler external surface. Next, if a heat sink is in contact with that surface, the heat energy will again flow, via conduction, across the interfacing surfaces to the cooler adjacent heat sink. The heat energy then flows through the heat sink, via conduction, to its cooler external, or internal surfaces exposed to a replenishable fluid. At this point, the heat energy is transferred, via convection and radiation, to the cooler ambient fluid. However, there are several real and practical, limitations that influence the flow of heat energy. First, and probably, most important is that there is a discrete, and relatively fixed, available temperature difference. Most electronic semiconductor components will not operate reliably when their internal active (junction) surface exceeds 150° C. and the generally available cooling fluids typically have an initial, entering ambient temperature of 25° to 50° C. Admittedly, an end user could use some form of a refrigeration cycle to sub-cool the fluid, but the economic penalty imposed usually limits this to a last resort solution.

The next limiting factor is imposed by the practical characteristics of cooling fluids available to the end user. Generally air (as a gas), water or other liquid compounds are used. Each fluid has fixed physical parameters that must be considered and accommodated with respect to the flow of heat. For example, dense fluids (like water) can absorb large amounts of heat energy in a small volume. Conversely, a gas (like air) can only absorb smaller amounts of heat energy in a large volume. Finally, the solid materials that comprise the requisite conductive path, from the heat source to the cooling fluid, have their own fixed physical parameters, such as thermal conductivity.

It is within the constraints imposed by all of the above that a heat sink operates. A heat sink's relative performance is characterized by the term "thermal resistance", (Θ), which essentially reflects these constraints. The formula is expressed:

$$\Theta=\frac{\Delta T}{Q}$$

where ΔT is the available temperature gradient and Q is the heat energy to be dissipated. When the amount of heat energy is relatively low, and a reasonable temperature gradient exists, air is usually the preferred cooling medium. Various types of heat sinks have been designed for operation with this fluid. They range from simple stamped metal shapes to progressively larger, and more complex, extrusions and fabricated assemblies. At some point, however, the amount of heat energy to be transferred exceeds the ability of an air cooled heat sink. Large amounts of energy require large amounts of exposed surface area. Large surface area requires large conductive supporting structures to distribute the heat energy. Large conductive structures have long thermal paths. Eventually, the conductive path losses exceed the gains of more convective (and radiative) surface area.

At this point, a liquid cooled heat sink is utilized. As explained earlier, a liquid can absorb large amounts of heat energy at relatively low temperature gradients. As a result, the conductive thermal path is usually the limiting factor, when the amount of heat energy is high or the temperature gradient is low. Initially, liquid cooled heat sinks were fabricated out of copper for this reason. Copper has a

relatively high. thermal conductivity and was widely used in liquid systems by virtue of its ease of fabrication. FIGS. **1** and **2** illustrate a conventional liquid cooled heat sink **10** having a copper block **12** which is mounted on a mounting plate or base **14**. The base **14** typically includes mounting holes **16** as well as a centering hole **18** for locating the heat generating device. The liquid cooled heat sink also includes inlet and outlet pipes **20**, **22**.

Another type of conventional liquid cooled heat sink is shown in FIGS. 3–5. This copper heat sink **40** includes a set of machine drilled conduits **44**, **46**, **48** which act together to form the passageway for the liquid coolant. Conduit **46** forms the connecting channel at one end of the heat sink and runs perpendicular or transverse to the conduits **44**, **48**. Conduit **46** contains a plug **50** to prevent liquid from emptying out. At the end of the machined conduits, copper adapter pipes **52** are inserted and soldered, or brazed, in place. U-shaped connector pipes **54** an also be used to connect adjacent conduits. The liquid cooled heat sink **40** includes mounting holes **58** disposed in flange sections **56**.

These figures illustrate the practical shortcomings of current designs. Both designs require extensive machining and have a significant potential for leaks because of either large planar bond lines or multiple joints and plugs used to connect internal passages. Additionally, there is a measurable thermal loss (gradient) due to the distance (typically between 0.13"–0.50") the heat energy must traverse to the cooling fluid. Another shortcoming is that copper is a relatively costly material and thus the designs have a high unit cost. Consequently, there are other liquid cooled designs that attempt to reduce the unit cost by either using less expensive materials along with simpler, less complex, fabrication techniques.

FIGS. **6** and **7** disclose another conventional liquid cooled heat sink **60**. In this type of liquid cooled heat sink, the aluminum block **62** has been extruded and the copper tubing **64** is disposed on the back side of the heat sink.

FIGS. **8** and **9** illustrate yet another version of a liquid cooled heat sink **70**. In this version, the copper tube **74** is sandwiched between two aluminum blocks **72**. The fluid passages are made from a singular piece of copper tubing that has been bent into a multiple of parallel cooling passages. The aluminum body (for mounting of the heat generating devices) is extruded to minimize fabrication costs.

FIGS. **6** and **7** illustrate a cold plate **60** that is made from one piece of aluminum **62** with grooves to hold the tubing **64**. FIGS. **8** and **9** show a cold plate **70** that consists of two pieces of aluminum **72** with the tubing **74** "sandwiched" between them. In each case, a heat conducting compound, such as thermal grease or adhesive is used to eliminate the air gaps between the extruded body and the tubing. While these designs are less expensive to construct, they are also less effective in the removal of heat energy. They are made with aluminum, a less conductive material than copper and they introduce an additional interface to the flow of the heat. The thermal compound is necessary to fill the gap between the tube and the body. While this compound is significantly better for transferring heat than air, it adds another temperature gradient to the detriment of performance of the heat sinks. As can be seen clearly from FIG. **10**, the heat generated by electronic components **90** must be transferred through the block **82** and then the interface **88** by conductivity and then removed via the cooling liquid flowing through the tubes **84**.

In all of the prior art liquid cooled heat sinks, the heat transfer does not occur by direct conduction from the heat generating component to the liquid containing passage.

These heat sinks include a measurably large thickness of solid material and, in some designs, interface compounds that add a commensurately large temperature gradient to the flow of heat energy. These features essentially limit the amount of the heat energy that can be effectively removed, or transferred, in these designs.

SUMMARY OF THE INVENTION

The present invention relates to a liquid cooled heat sink that efficiently transfers the heat energy from the heat generating components. The heat sink includes channels, or grooves, that are formed in at least one surface of the base member. The channels contain the fluid conduits that have been constrained by the channels. The fluid filled conduits have a planar surface which is substantially coplanar with the surface of the heat sink which is in contact with the heat generating component. It is this structure that substantially improves the heat sink's effectiveness in removing heat energy. There is only a minimal thickness (0.03" instead of 0.38") of solid conduit material between the heat source and the cooling fluid medium. The much larger thicknesses as well as the gap filling thermal compound of the prior art have been eliminated in all sections where the conduit contacts the heat generating component. The elimination of these "losses", in the thermal path, thus results in an improvement in the liquid cooled heat sink's performance. In addition, the gain in performance is accomplished without incurring additional costs in manufacturing the preferred embodiment.

Further, improved localized heat transfer within the fluid conduits is accomplished by providing the channels with local deformations which are incorporated into the surface of the fluid conduit as it is pressed into place.

It is an object of the present invention to provide a liquid cooled heat sink which provides better heat transfer performance than conventional heat sinks.

It is another object of the present invention to provide a method of manufacturing of the heat sink which is economical and which positions the fluid conduit adjacent to an electronic component to be disposed thereon.

It is still another object of the present invention to provide a structure for localized improved heat transfer in selected regions of the heat sink.

The above mentioned objects are achieved by providing a liquid cooled heat sink for cooling electronic components comprising a heat sink base member having channels formed in at least one surface thereof and a fluid conduit disposed in the channels. The fluid conduit has a flattened surface which is substantially coplanar with the surface of the heat sink base member having the channels therein.

The above mentioned objects are also achieved by a method of manufacturing a liquid cooled heat sink comprising the steps of providing a heat sink base member having channels formed in at least one surface of the heat sink base member; providing a thermally conductive adhesive in the channels; inserting a fluid conduit into the channels; and pressing the fluid conduit into the channels so as to deform the fluid conduit into a shape where one surface of the fluid conduit is substantially coplanar with the surface of the heat sink base member which has the channels formed therein.

BRIEF DESCRIPTION OF THE DRAWINGS

The above objects and features of the present invention will be apparent to those skilled in the art from the following description of the preferred embodiments thereof when considered in conjunction with the appended drawings in which:

FIG. 1 is a top view showing a conventional liquid cooled heat sink and mounting structure.

FIG. 2 is a side view of the conventional liquid cooled heat sink of FIG. 1.

FIG. 3 is a top view of another conventional liquid cooled heat sink and mounting structure.

FIG. 4 is a side view of the liquid cooled heat sink of FIG. 3.

FIG. 5 is an end view of the liquid cooled heat sink according to FIG. 3.

FIG. 6 is a top view of yet another conventional liquid cooled heat sink.

FIG. 7 is an end view of the conventional liquid cooled heat sink of FIG. 6.

FIG. 8 is a top view of still another conventional liquid cooled heat sink.

FIG. 9 is an end view of the liquid cooled heat sink of FIG. 8.

FIG. 10 is a cross sectional view of a conventional liquid cooled heat sink having an electronic component mounted thereon.

FIG. 11 is a cross sectional view of a liquid cooled heat sink having an electronic component mounted thereon according to a first embodiment of the present invention.

FIG. 11A is an exploded, cross sectional view of one of the channels formed in the heat sink of FIG. 11 and a conduit adapted for insertion into the channel.

FIG. 12 is a top view of a liquid cooled heat sink according a second embodiment of the present invention.

FIG. 13 is a top view of a liquid cooled heat sink according to a third embodiment of the present invention.

FIG. 14 is a cross sectional view of the liquid cooled heat sink taken along line XIV—XIV in FIG. 13.

FIG. 15 is a side view of the liquid cooled heat sink according to the third embodiment of the present invention.

FIG. 16 is a side view of a series of electronic components which are disposed on either surface of liquid cooled heat sinks of FIG. 15, to form a stacked assembly according to the present invention.

FIG. 17 is a top view of a fluid conduit disposed in a channel which is locally deformed by a turbulating structure.

FIG. 18 is a cross sectional view taken along line XVIII—XVIII of FIG. 17 showing the fluid conduit deformation.

FIG. 19 is another embodiment of a fluid conduit which is locally deformed according to the present invention.

FIG. 20 is a cross sectional view taken along line XX—XX in FIG. 19.

FIG. 21 is a cross sectional view taken along line XXI—XXI of FIG. 19.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 11 illustrates a liquid cooled heat sink 100 according to a first embodiment of the invention. The liquid cooled heat sink includes an aluminum base member 102 which includes substantially U-shaped channels 104, 106 disposed in one side of the aluminum base member 102. Preferably, the channels 104, 106 have a substantially semi-circular bottom portion 103. Here, the bottom portions 103 are made up of two laterally spaced 90 degree arcs, each of radius R, as shown in FIG. 11A for channel 104. The channels 104, 106 have upper side walls 105 which taper towards each other as they project toward the open end 107 of the

channels **104**, **106**. The height, H, of the channels **104**, **106** is preferably about 80 percent of the outer diameter, D, of the copper tubes **114**, **116**. The centers of the arcs are laterally spaced a distance, L, such that $2R+L=S_{Lower}=1.05D$, where $R=D/2$ and L is 0.05D. Further, the span S_{Upper}, across the open end **107** of the channels **104**, **106** is equal to the diameter of the tubes **114**, **116**, i.e., $S_{Upper}=D$. Thus, the span, S_{Upper}, across the upper end **107**, or mouth, of the channel is less than the span, S_{Lower} across the bottom, or lower, substantially semi-circular bottom portion **103** of the channel **104**. It is noted that the bottom portion **103** of the channel **104** may be entirely semi-circular and in such case the radius, R', of such bottom portion should be about 2.5 percent greater than the diameter, D; i.e., 2R' should be about 5 percent greater than D. Copper tubes **114**, **116** are disposed in the channels **104**, **106**. More particularly, the copper tubes **114**, **116** are rolled and pressed into the channels **104**, **106** so that they have upper surfaces which are flat and substantially coplanar with the upper surface of the aluminum base member **102**, as shown in FIG. **11**. It is noted that the narrower sides at the upper end, **107** or mouth of the channel **104**, **106** will pinch the sides of the tubes **114**, **116** to firmly grasp and retain the tubes **114**, **116** within the channels **102**, **104**. Further, the copper tubes **114**, **116** are attached to the aluminum base member **102** by an adhesive **108** which covers the curved surface of the tubes and provides good thermal conductivity between the base member **102** and the tubes **114**, **116**. The adhesive **108** can be an epoxy, a thermally conductive silicone rubber or any other type of adhesive which will provide good thermal conductivity between the tubes **114**, **116** and the aluminum base member **102**. It is important that the adhesive be supplied in a large enough quantity to completely cover the curved surface of the tube and remove any air gaps between the tubes **114**, **116** and the base member **102**. It is noted that the pinching action resulting from the narrower span across the mouth of the channel, together with the adhesive, provides the requisite forces necessary to retain the tubes within the channels in the presence of the heat transferred through the tubes and the base member **102**.

The tubes **114**, **116** include a flat surface **110** which is substantially coplanar with the upper surface **118** of the aluminum base member **102**.

Disposed in direct contact with the tubes **114**, **116** and the upper surface **118** of the base member **102** is an electronic component **112**. The flat surface of the heat sink **100** provides for good thermal conductivity between the electronic component **112** and the liquid cooled heat sink **100**. With this structure, heat transfer is allowed to pass directly into the fluid conduits without passing through other components.

FIG. **12** illustrates a further embodiment of the present invention. In this embodiment a liquid cooled heat sink **120** is shown. The heat sink **120** includes an aluminum block member **122** having a copper tube **124** disposed in channels formed in a surface of the aluminum block **122**. The copper tube includes an inlet and outlet **126**, **128**. Mounting holes **130** are also provided for mounting electronic components across the four passes of the copper tube **124** disposed in the aluminum block **122**.

FIGS. **13**–**15** illustrate a further embodiment of the present invention. In this embodiment, a liquid cooled heat sink **150** is provided. The heat sink **150** comprises an aluminum block **152** having a copper tube disposed therein. The copper tube includes various straight sections **154**, **156**, **158** and **160** which are disposed in channels formed in a surface of the aluminum block **152**. These sections are joined by connecting portions **162**, **164** and **166**.

As can be seen clearly from FIG. 14, the aluminum block or base member **152** includes channels which are formed in opposite sides of the heat sink. This allows for electronic components to be mounted on either side of the heat sink **150**. The arrangement of the copper tube is such that section **154** is disposed below the aluminum block **152** as seen in FIG. 13. The U-shaped bend section **162** is then disposed at an angle so as to allow the next section of the tube **156** to be disposed in the upper surface of the heat sink **152**. Likewise U-bend **164** is also disposed at an angle so that it connects section **156** with tube section **158** which is disposed below the heat sink as seen in FIG. 13. Finally U-bend section **166** is also disposed at an angle to connect tube section **158** with tube section **160**. Tube section **160** is disposed below the heat sink block **152**. Thus it is seen that both surfaces of the heat sink can be utilized for removing heat from electronic components which are disposed on both sides of the heat sink **150**.

FIG. **16** illustrates a stacked arrangement of electronic components which are spaced apart by liquid cooled heat sinks such as that shown in FIGS. **13–15**. The stacked arrangement **200** includes heat sinks **202** that are disposed adjacent to the electronic component **204**. Some heat sinks such as heat sink **206** include extensions **208** for various electrical connections (not shown).

The fluid's convective heat transfer rate is determined by its absorptive characteristics and the fluid passage geometry. A relatively smooth, unchanging uniform interior surface, such as a machined groove or tube will result in minimal disturbance of the fluid's flow. Conversely, a very rough surface, changes in fluid direction or passage cross section will induce disturbances in the fluid flow. Whenever a disturbance occurs, it will locally improve the fluid's heat transfer rate while slightly increasing the pressure losses. If there is no subsequent changes in the passage geometry, the disturbances will subside and the fluid's heat transfer rate will return to its prior value.

FIGS. **17** and **18** illustrate such an enhanced localized heat transfer mechanism according to the present invention. When liquid cooled heat sinks are used in various applications, the thermal heat flux is generally concentrated within a few locations along the thermal interface plane. In prior art fabricated designs, additional performance has been provided by machining additional cooling passages within the part. In conventional composite designs, additional performance was provided by using interior finned tubing or adding flow turbulence inserts into the fluid conduit in the heat sink. All of these methods for providing enhanced localized heat transfer incurred additional costs for the heat sink and also severely impacted the fluid pressure drop through the fluid conduits.

FIGS. **17–18** illustrate one embodiment for creating a localized cross sectional area change in the fluid conduit passage by selectively contouring the aluminum base member channel. Thus, in FIG. **17** an aluminum block section **240** is provided with a tube **246**. The normal width of the tube is shown at the portion illustrated by reference numeral **242**. The expanded width section, shown at **244**, is what results after the fluid conduit has been inserted and pressed into the channel. It is noted that the width change at **244** has been exaggerated for purposes of illustration. The enlarged width is caused when the round copper tube **246** is inserted into the channel and contacts a ridge **248** which extends transverse to the direction of the fluid conduit **246**. This ridge **248** causes a local deformation of the tube **246** as shown in the region **250**. This creates a cross sectional area change in the fluid passage which improves the localized

fluid heat transfer coefficient because of the disruption in the boundary layer and because of variations in the fluid velocity. The main feature of this design is that the enhanced performance is selectively located and consequently the liquid cooled heat sink's overall pressure drop is minimized.

FIGS. 19 and 20 illustrate another embodiment of the localized heat transfer improvement. FIG. 19 illustrates an aluminum block 260 having a copper tube 262 disposed therein. The block member 260 includes a bump or protrusion 264 in the surface of the channel. This causes a matching, localized bump 266 in the surface of tube 262.

FIG. 21 illustrates a cross section of FIG. 19 and shows the local deformation 266 caused by the protrusion 264.

It is also possible to use square or D-shaped in cross section tubing as long as the channels formed in the base member are provided with a contour to accept this type of tubing. Round cross sectional tubing is preferred because other shaped tubing is difficult to bend into the connections for the multipass designs.

Other types of materials, besides aluminum and copper are also possible depending on the particular application which is being used.

The method for forming the high contact heat sink is as follows. First, an aluminum block is cast or extruded in the desired shape so that it includes grooves for receiving the copper tubes therein. An alternative to casting or extruding the aluminum block would be to use a solid aluminum block and machine the channels that would receive the copper tubes as well as possibly even machining the final block shape.

Following the step of providing an aluminum block with the channels for receiving the copper tube therein, an adhesive material is put in the channels. The adhesive material can be an epoxy, a thermally conductive silicon rubber or any other type of adhesive which will provide a good thermal interface.

A round cross section copper tube is then inserted into the channels. A flat punch or press is then used to flatten one side of the tube while simultaneously forcing the remaining portion of the copper tube into contact with the adhesive and the channel walls. The object during this procedure is to eliminate all air gaps between the copper tube and the aluminum block to thereby provide a good conduction path for heat transfer.

Once the flat punch or press is removed following the tube compression step, there may be some spring back of the flattened tube wall or other irregularities which have been formed in the tube wall surface, such as crinkling of the tube surface. As a result, a further processing step may be required. In this step, the surface of the aluminum block and the surface of the flattened tube may be machined flat to provide a smooth coplanar surface. This surface will enhance thermal conductivity and thus improve the heat transfer from the heat generating component to the heat sink.

After the machining step, the heat sink can be mounted in a known manner. One type of mounting includes attaching the electronic component to the heat sink by screws.

Other methods of manufacture of the heat sink are also possible and are considered to part of this invention. One such alternative embodiment includes starting with a pre-shaped tube such as a D-shaped (in cross-section) tube and then casting the aluminum block around the D-shaped tube which has been preformed or bent into the desired channel shape. The cast block is then machined down to expose the flat surface of the tube so that it is coplanar with the surface of the aluminum block.

The present invention has been described in connection with certain structural embodiments and it will be understood that various modifications can be made to the above-described embodiments without departing from the spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. A liquid cooled heat sink for cooling a heat generating component in contact therewith, comprising:

a heat sink base member having an open ended channel formed in one surface thereof, said channel including a curved lower wall and a pair of side walls, each sidewall having a first end continuous with said curved lower wall and a second end terminating at said surface, said sidewalls being tapered from said first ends to said second ends, the open end of the channel having a span less than a span across a lower portion of the channel; and

a fluid conduit constructed of a thermally conducting material and disposed in said channel, said fluid conduit being disposed in said channel and having an outer span greater than the span across the open end of the channel for maintaining said fluid conduit in said channel by a friction fit formed between said side walls and said fluid conduit, said fluid conduit having a flattened surface which is substantially coplanar with said one surface of said heat sink base member, the heat generating component being disposed in use in direct contact with said one surface of said heat sink base member and in overlying abutting relation with said flattened surface for establishing direct thermal contact between the heat generating component and said flattened surface.

2. A heat sink as claimed in claim 1, further comprising an adhesive disposed in said channel for holding said fluid conduit in said heat sink base member and for providing good thermal conductivity between a heat generating component and said fluid conduit.

3. A heat sink as claimed in claim 1, wherein said heat sink base member includes channel on two sides of said heat sink base member.

4. A heat sink as claimed in claim 3, wherein said channels are disposed on opposite sides of said heat sink base member.

5. A heat sink as claimed in claim 4, wherein said fluid conduit is disposed on alternative sides of said heat sink base member as the fluid conduit is positioned in said channel.

6. A heat sink as claimed in claim 1, wherein said heat sink base member is made of at least one of aluminum and aluminum alloy and said fluid conduit is made of at least one of copper and copper alloy.

7. A heat sink as claimed in claim 1, wherein at least one of said channels includes a local deformation rising from a surface of said one channel and said fluid conduit includes a local deformation directed toward the inside of said fluid conduit, said local deformation in said one channel and said local deformation in said fluid conduit being disposed adjacent to one another.

8. A liquid cooled heat sink for cooling heat generating components, comprising:

a heat sink base member having channels formed in at least one surface thereof;

a fluid conduit disposed in said channels, said fluid conduit having a flattened surface which is substantially coplanar with the surface of the heat sink base member having the channels therein, wherein at least one of said channels includes a local deformation rising from a surface of said at least one channel and said fluid conduit includes a local deformation directed toward the inside of said fluid conduit, said local deformation in said at least one channel and said local deformation in said fluid conduit being disposed adjacent to one another, and wherein said local deformation in said at least one channel is a ridge extending transverse to the direction of said fluid conduit.

9. A liquid cooled heat sink for cooling a heat generating component in contact therewith, comprising:

a heat sink base member having an open ended channel formed in one surface thereof, said channel including a curved lower wall and a pair of side walls, with each sidewall having a first end continuous with said curved lower wall and a second end terminating at said surface, said sidewalls being tapered from said first ends to said second ends so that the open end of the channel has a span less than a span across a lower portion of the channel; and

a fluid conduit constructed of thermally conductive material and disposed in said channels, said fluid conduit having a flattened surface which is substantially coplanar with said one surface of the heat sink base member and in direct contact with the heat generating component, wherein said channel includes a local deformation rising from a surface of said channel and said fluid conduit includes a deformation directed toward the inside of said fluid conduit, said local deformation in said channel and said local deformation in said fluid conduit being disposed adjacent to one another.

* * * * *

10. A heat sink for cooling a heat generating component in contact therewith, comprising:

a heat sink base member having an open ended channel formed in a first surface thereof, said open ended channel including a curved lower wall and a pair of side walls, each side wall having a first end continuous with said curved lower wall and a second end terminating at said first surface, said side walls being tapered inwardly from said first ends to said second ends, the second ends of said side walls having a span less than a span across a lower portion of said channel; and

a tubular fluid conduit constructed of a thermally conducting material and disposed in said channel, said fluid conduit having a starting diameter larger than the depth of the channel and being disposed in said channel by being deformed using the channel as a mold, wherein following deformation the portion of said fluid conduit formerly disposed above said channel has a flattened surface which is substantially coplanar with said first surface of said heat sink base member, whereby the heat generating component may be disposed in direct contact with said first surface of said heat sink base member and with said flattened surface of said conduit for establishing direct thermal contact between said heat generating component and said flattened surface.

11. The heat sink according to claim 10, wherein after deformation of said tubular conduit, an outer span of the portion of the fluid conduit disposed in said channel is greater than the span of said open end of said channel.

12. The heat sink according to claim 10, further comprising:

an adhesive disposed in said channel.

13. The heat sink according to claim 12, wherein after deformation of said tubular conduit, an outer span of both the portion of the fluid conduit disposed in said channel and the adhesive disposed in said channel is greater than the span of said second ends of said side walls of said channel.

14. The heat sink according to claim 10, further comprising a further open ended channel formed in a second surface of the base member, said further channel including a curved lower wall and a pair of side walls, each side wall having a first end continuous with said curved lower wall and a second end terminating at said second surface, said side walls being tapered inwardly from said first ends to said second ends, the second ends of said side walls having a span less than a span across a lower portion of said further channel.

15. The heat sink according to claim 14, wherein said first surface and said second surface of said heat sink base member are opposite one another.

16. The heat sink according to claim 10, wherein said heat sink base member is made from one of aluminum and aluminum alloy; and

said fluid conduit is made from one of copper and copper alloy.

17. The heat sink according to claim 10, wherein a cross section of said tubular conduit is one of d-shaped, circular, and square.

18. The heat sink according to claim 17, wherein said cross section is circular.

19. A method of forming a heat sink suitable for cooling a heat generating component, comprising the steps of:

providing a heat sink base member having an open ended channel formed in a first surface thereof, said channel including a curved lower wall and a pair of side walls, each side wall having a first end continuous with said curved lower wall and a second end terminating at said first surface, said side walls being tapered inwardly from said first ends to said second ends, the open end of said channel having a span less than a span across a lower portion of said channel;

providing a tubular fluid conduit being constructed of a thermally conducting material and having a diameter larger than a depth of said channel;

positioning said fluid conduit into said channel so that a portion of the fluid conduit extends above the first surface of the heat sink base member; and

deforming said fluid conduit using the channel as a mold for rendering said portion substantially coplanar with the first surface of said heat sink base member, for disposing and maintaining said fluid conduit in said channel, whereby the heat generating component may be disposed in direct contact with said first surface of said heat sink base member and with said flattened surface of said conduit for establishing direct thermal contact between said heat generating component and said flattened surface.

20. The method according to claim 19, wherein an outer span of the portion of said fluid conduit disposed in said channel is greater than the span of said open end of said channel.

21. The method according to claim 19, further comprising the step of:

disposing an adhesive in said channel at least one of before, during and after said positioning step.

22. The method according to claim 21, wherein after deformation of said tubular conduit, a combined outer span of both the portion of the fluid conduit disposed in said channel and the adhesive disposed in said channel is greater than the span of said open end of said channel.

23. The method according to claim 19, wherein said heat sink base member is made from one of aluminum and aluminum alloy; and

said fluid conduit is made from one of copper and copper alloy.

24. The method according to claim 19, wherein a cross section of said tubular conduit is one of d-shaped, circular, and square.

25. The method according to claim 23, wherein said cross section is circular.

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26. A method of forming a heat sink suitable for cooling a heat generating component, comprising the steps of:

providing a heat sink base member having a first surface and a second surface, wherein a first open ended channel is formed in said first surface, a second open ended channel is formed in said second surface, each of said channels including a curved lower wall and a pair of side walls, each side wall having a first end continuous with said curved lower wall and a second end terminating at said one surface, said side walls being tapered inwardly from said first ends to said second ends, the open ends of said channels having a span less than a span across a lower portion of said channels;

providing a first tubular fluid conduit and a second tubular fluid conduit, each conduit being constructed of a thermally conducting material and having a diameter larger than a depth of said channels;

positioning said first conduit into said first channel so that a portion of the first conduit extends above the first surface of the heat sink base member;

positioning said second conduit into said second channel so that a portion of the second conduit extends above said second surface of the heat sink base member;

deforming said first conduit using said first channel as a mold for rendering said portion of said first conduit substantially coplanar with said first surface of said heat sink base member for disposing and maintaining said first conduit in said first channel; and

deforming said second conduit using said second channel as a mold for rendering said portion of said second conduit substantially coplanar with said second surface of said heat sink base member for disposing and maintaining said second conduit in said second channel, whereby a first heat generating component may be disposed in direct contact with said

first surface of said heat sink base member and with said flattened surface of said first conduit for establishing direct thermal contact between said first heat generating component and said flattened surface of said first fluid conduit, and whereby a second heat generating component may be disposed in direct contact with said second surface of said heat sink base member and with said flattened surface of said second conduit for establishing direct thermal contact between said second heat generating component and said flattened surface of said second fluid conduit.

27. The method according to claim 26, wherein after the deforming step, said first conduit disposed in said first channel has a first outer span, said second conduit disposed in said second channel has a second outer span, wherein at least one of said first outer span and said second outer span is greater than the span of said open end of said first channel and the span of said open end of said second channel, respectively.

28. The method according to claim 26, further comprising the step of:

disposing an adhesive in at least one of said first channel and said second channel at least one of before, during and after said positioning steps.

29. The method according to claim 28, wherein after deformation of said first and second tubular conduits, said portion of the first conduit and said adhesive disposed in said first channel has a first outer span, said portion of the second conduit and said adhesive disposed in said second channel has a second outer span, wherein at least one of said first outer

span and said second outer span is greater than the span of said open end of said first channel and said open end of said second channel, respectively.

30. The method according to claim 26, wherein said heat sink base member is made from one of aluminum and aluminum alloy; and

said fluid conduit is made from one of copper and copper alloy.

31. The method according to claim 26, wherein a cross section of at least one of said tubular conduits is one of d-shaped, circular, and square.

32. The method according to claim 26, wherein said cross section is circular.

ABSTRACT

A liquid cooled heat sink for cooling heat generating components. The heat sink has a base member with open ended channels formed in at least one surface thereof. The open ends of the channels have a span less than a span across a lower portion of the channels. A fluid conduit is disposed in said channels. The fluid conduit has an outer span greater than the span across the open ends of the channels and a flattened surface which is substantially coplanar with the surface of the heat sink base member having the channels therein.

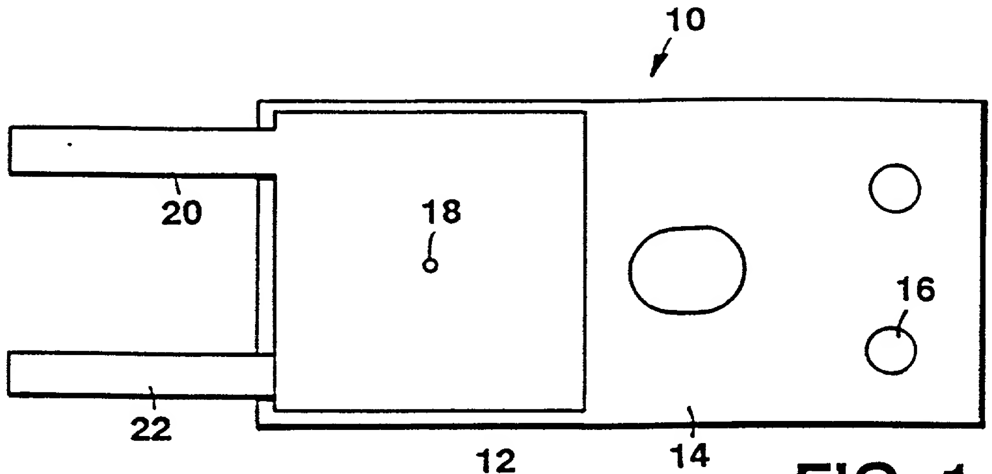

FIG. 1
(PRIOR ART)

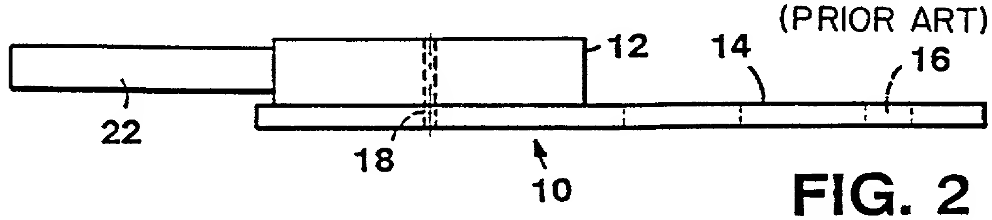

FIG. 2
(PRIOR ART)

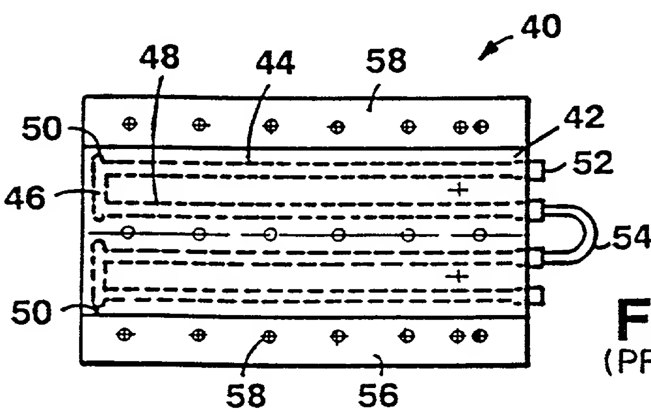

FIG. 3
(PRIOR ART)

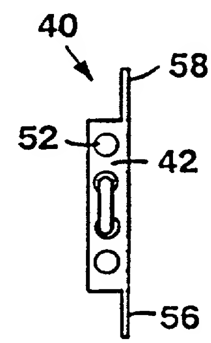

FIG. 5
(PRIOR ART)

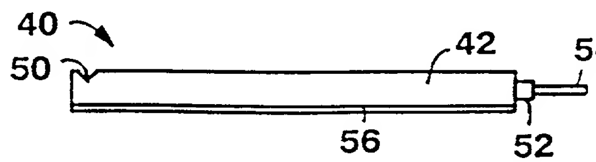

FIG. 4
(PRIOR ART)

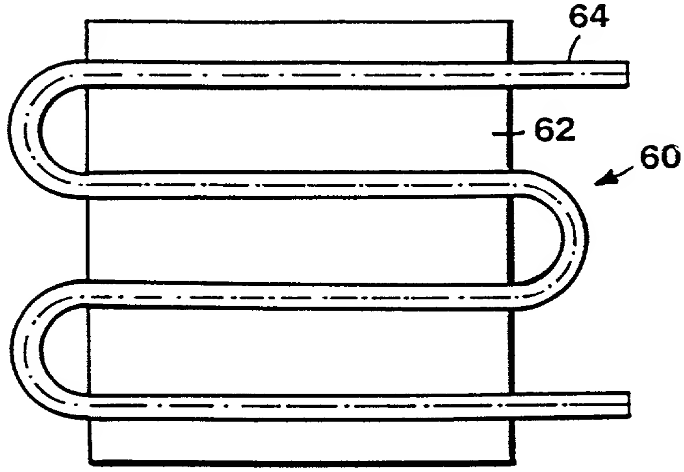

FIG. 6
(PRIOR ART)

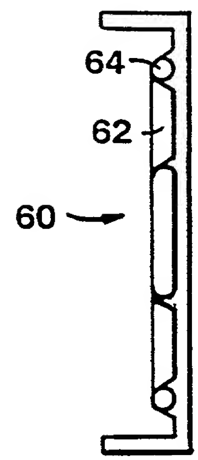

FIG. 7
(PRIOR ART)

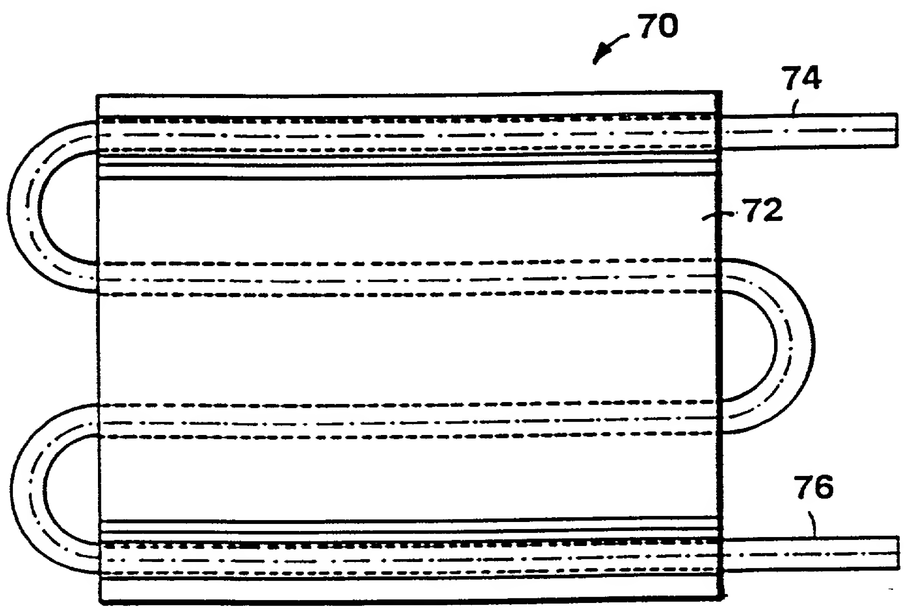

FIG. 8
(PRIOR ART)

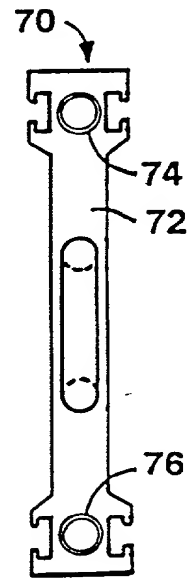

FIG. 9
(PRIOR ART

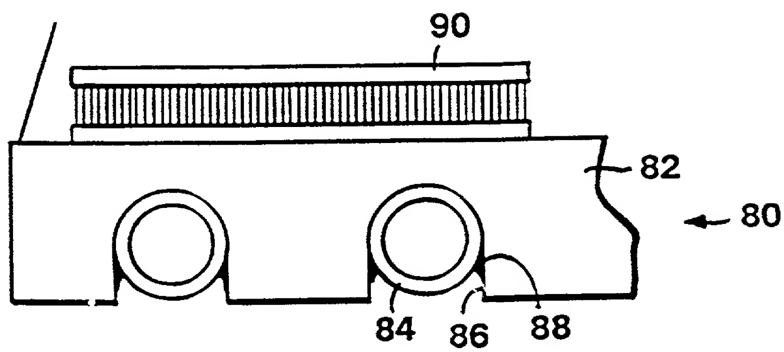

FIG. 10
(PRIOR ART)

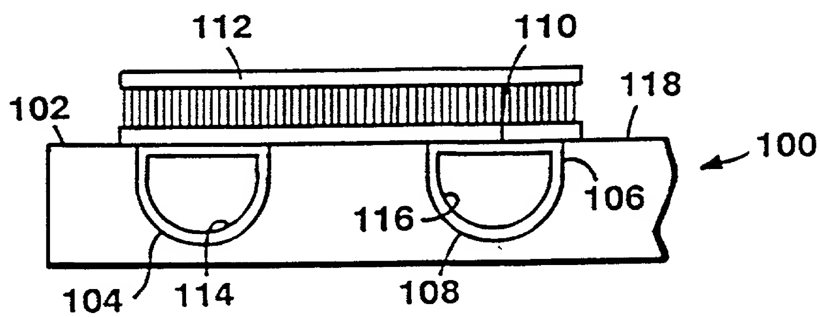

FIG. 11

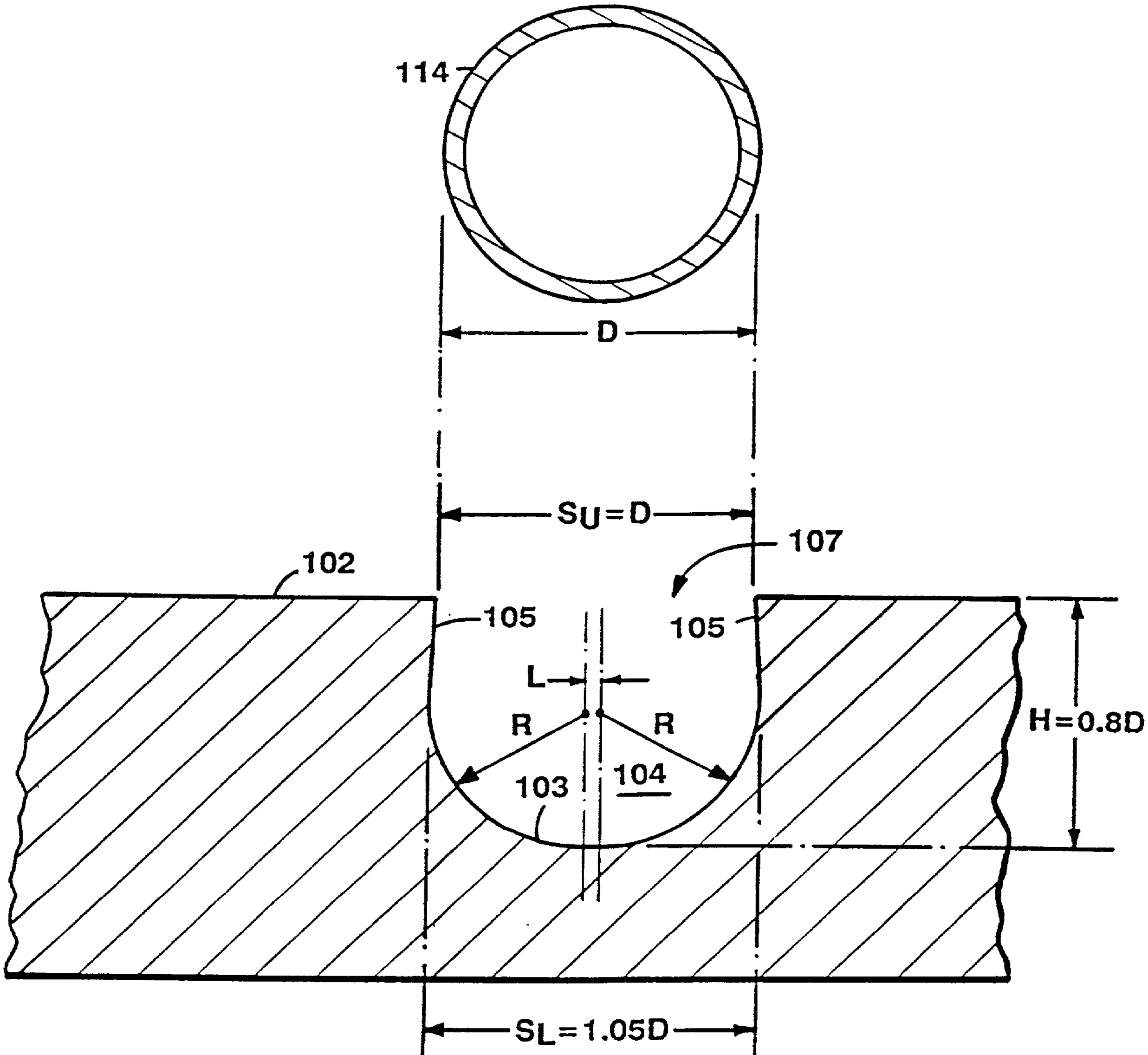

FIG. 11A

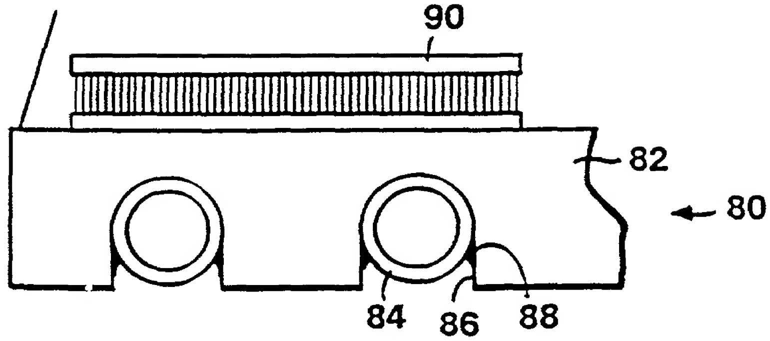

FIG. 10
(PRIOR ART)

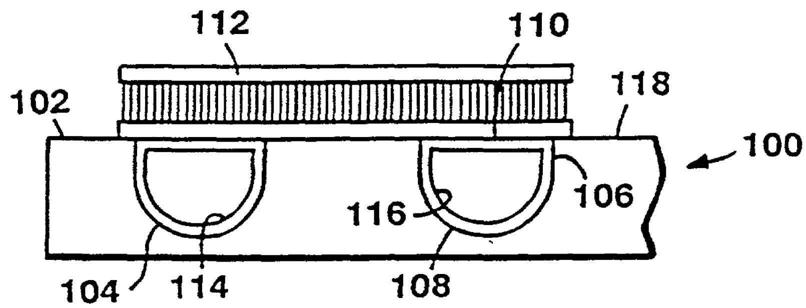

FIG. 11

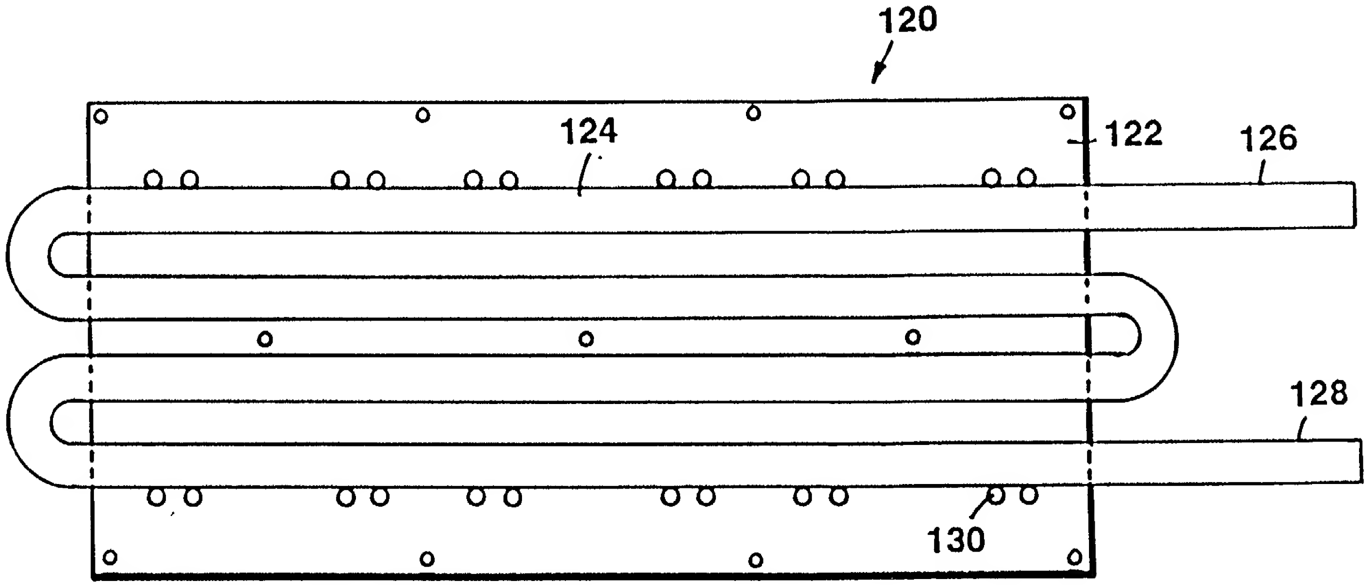

FIG. 12

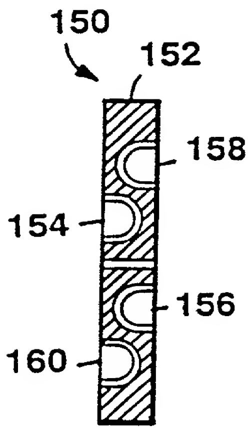

FIG. 14

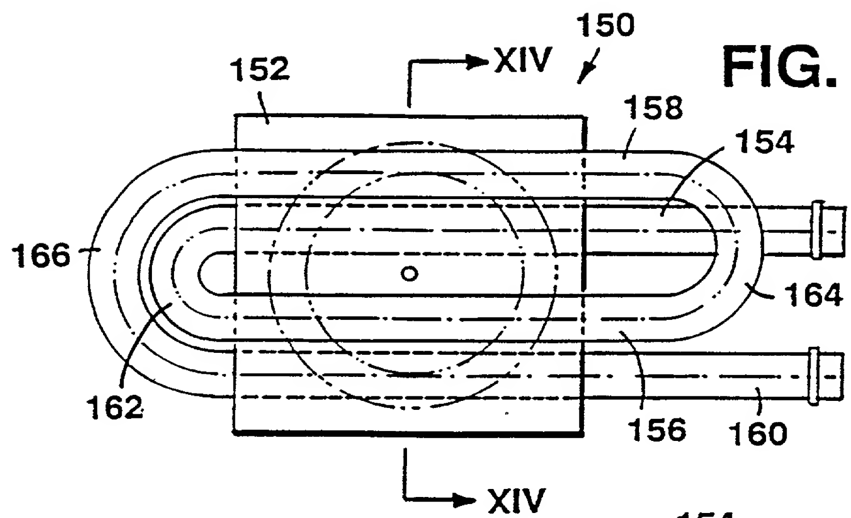

FIG. 13

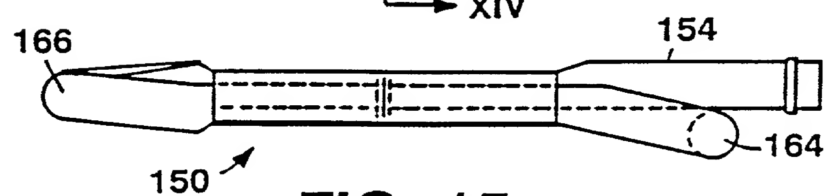

FIG. 15

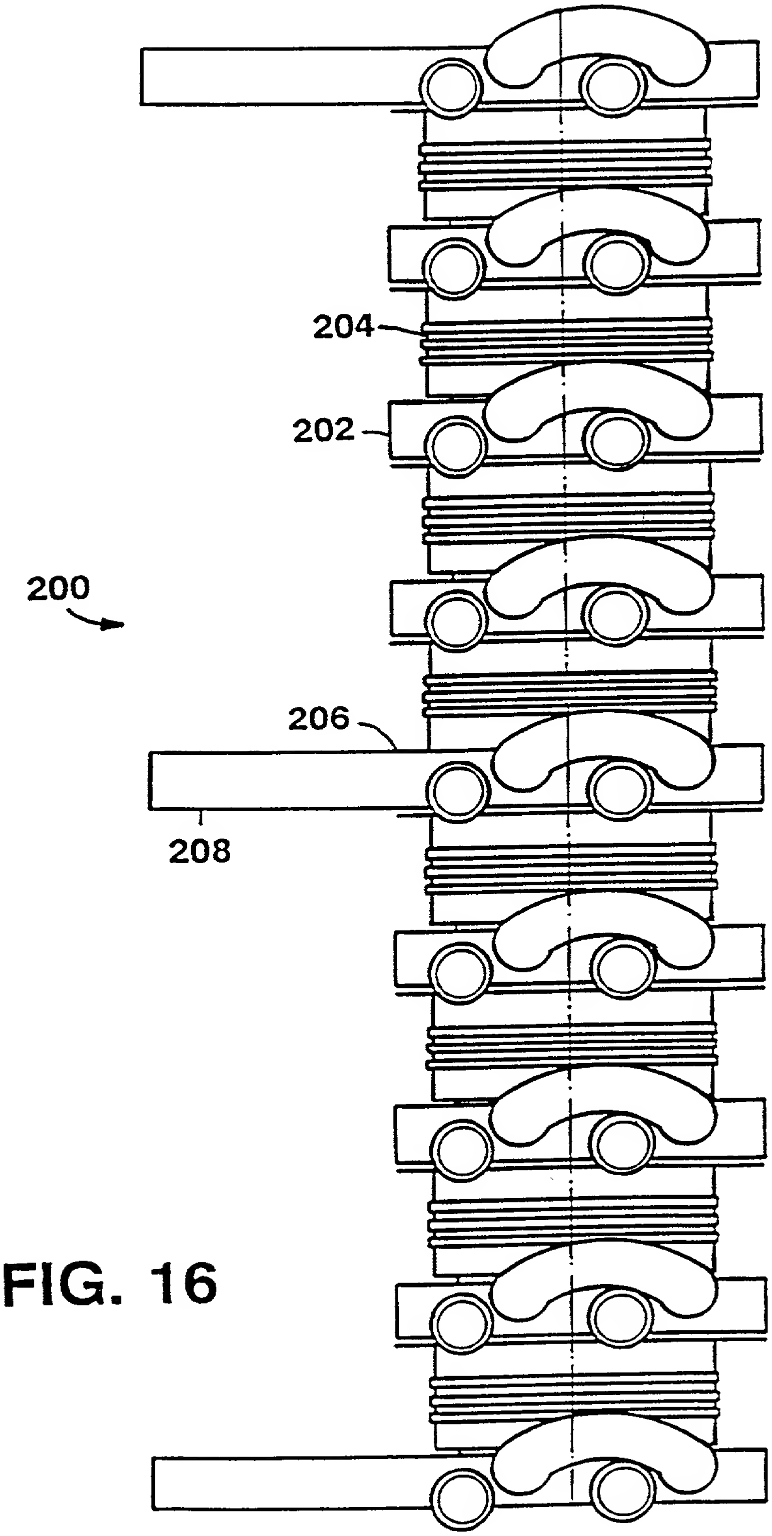

FIG. 16

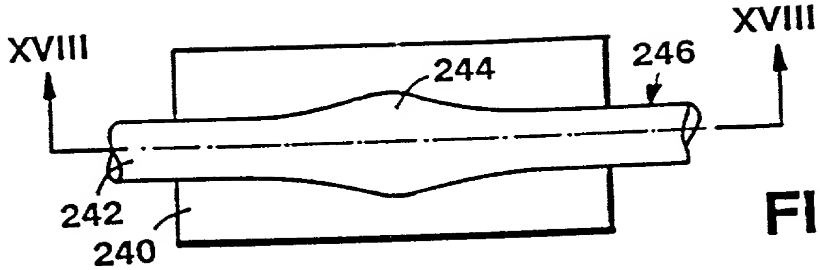

FIG. 17

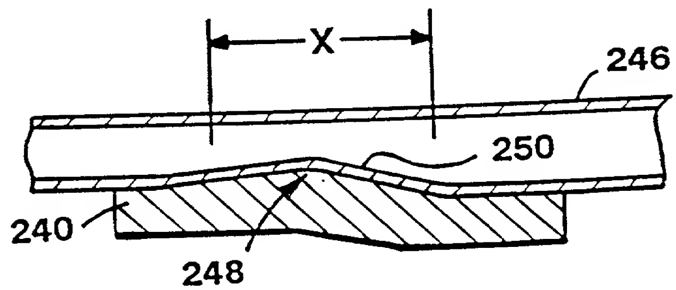

FIG. 18

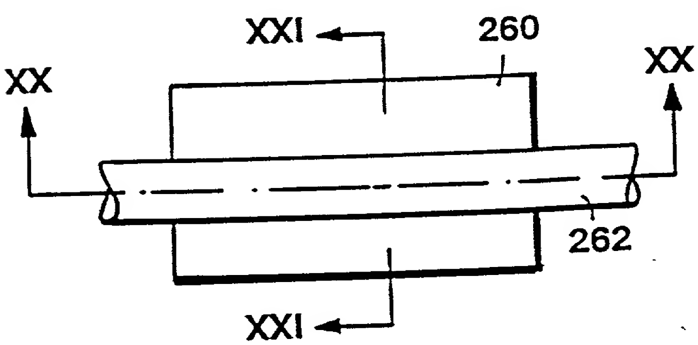

FIG. 19

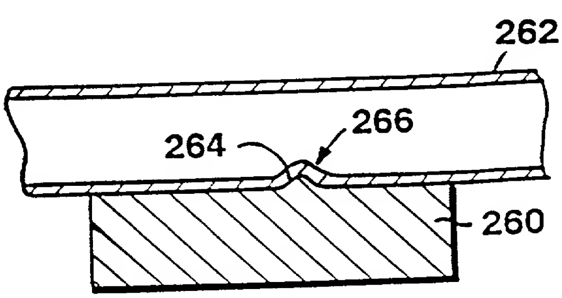

FIG. 20

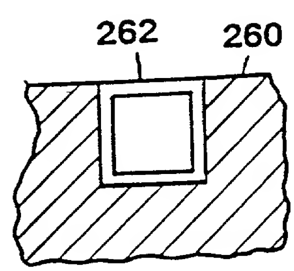

FIG. 21